REMARKS

In view of the above amendments and the following remarks, reconsideration and further examination are requested.

The specification and abstract have been reviewed and revised to make a number of editorial revisions. No new matter has been added. Enclosed is a marked-up copy of sections of the original specification and abstract labeled "**Version with Markings to Show Changes Made**" indicating the changes.

Proposed drawing amendments addressing the objections made by the Draftsperson are submitted herewith under a separate cover letter. These drawing amendments are editorial in nature and do not add new matter to the application. **In addition, new formal drawings incorporating the proposed drawing amendments are also enclosed herewith under a separate cover letter.**

In addition, claims 1-14 have been amended to make a number of editorial revisions. These revisions have been made to place the claims in better U.S. form. None of these amendments have been made to narrow the scope of protection of the claims, nor to address issues related to patentability and therefore, these amendments should not be construed as limiting the scope of equivalents of the claimed features offered by the Doctrine of Equivalents.

Claims 1 and 8 have been rejected under 35 U.S.C. §102(b) as being anticipated by Bodell (US 4,768,186). Claims 1 and 8 have also been rejected under 35 U.S.C. §103(a) as being unpatentable over Fujito (US 4,722,081) in view of Bodell. Claims 2, 4, 5, 9, 11 and 12 have been rejected under 35 U.S.C. §103(a) as being unpatentable over Bodell in view of LaGasse (US 5,373,383). Claims 3, 6, 7, 10, 13 and 14 have been indicated as containing allowable subject matter. The Applicants would like to thank the Examiner for this indication of allowable subject matter.

The above-recited rejections are respectfully traversed for at least the following reasons.

Claim 1 is patentable over Bodell and the combination of Fujito and Bodell, since claim 1 recites a transmission system having a transmitting end with an optical transmitter operable to convert a FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in an optical frequency spectrum through optical modulation using the

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FM modulated signal as an original signal to send the optical-intensity-modulated signal to a receiving end. Neither Bodell, nor the combination of Fujito and Bodell, disclose or suggest an optical transmitter as recited in claim 1.

Bodell discloses a communication system having a multiplexor 6 that multiplexes a number of signals and passes a resultant multiplexed signal to a frequency modulator 7. The frequency modulator 7 outputs a signal based on the multiplexed signal that is employed to intensity modulate an output of an optical transmitter 8. The optical transmitter 8 comprises a terminal 38 at which the signal of the frequency modulator 7 is received. The signal passes through a pair of directional couplers 39 and 40 before reaching a laser 41. The laser 41 outputs a light signal that is intensity modulated based on the signal. (<u>See</u> Figures 1 and 3, column 3, lines 42-54, and column 4, lines 45-64).

Based on the above description of Bodell, it is apparent that Bodell fails to disclose or suggest an optical transmitter as recited in claim 1, since there is no indication that the optical transmitter 8 is operable to convert a FM modulated signal into <u>an optical-intensity-modulated signal whose optical carrier component is suppressed in an optical frequency spectrum</u>. Instead, it appears that the optical transmitter 8 converts the signal from the frequency modulator 7 with a direct modulation scheme. This conclusion is supported by the fact that the signal received at the terminal 38 only passes through the pair of directional couplers 39 and 40 before reaching the laser 41. As a result, Bodell fails to disclose or suggest the invention as recited in claim 1.

In the combination of Fujito and Bodell, the Examiner relies on Fujito as disclosing the optical transmitter recited in claim 1. Fujito discloses an analog optical transmission system having a plurality of frequency modulators 1-1 through 1-N which modulate a plurality of signals, respectively. The plurality of modulated signals are combined by a combiner 2 which multiplexes the plurality of signals into a single signal which is then fed through an amplifier 3 and an adder 4 for power control. The single signal is then fed directly into a laser diode module 5 for transmission. The laser diode module 5 comprises a laser diode 50 connected via a coupler 54 to an optical fiber 10 as the transmission medium. (<u>See</u> Figures 1 and 2, and column 2, line 54 - column 3, line 37).

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Based on the above description of Fujito, it is apparent that Fujito fails to disclose or suggest an optical transmitter as recited in claim 1, since there is no indication that the laser diode module 5 is operable to convert a FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in an optical frequency spectrum. Instead, it appears that the laser diode 50 converts the signal from the adder 4 with a direct modulation scheme. This conclusion is supported by the fact that the signal received by the laser diode 50 is received directly from the adder 4. Therefore, Fujito fails to disclose or suggest the optical transmitter recited in claim 1.

Further, as discussed above, Bodell also fails to disclose or suggest the optical transmitter recited in claim 1. As a result, the combination of Fujito and Bodell fails to disclose or suggest the invention as recited in claim 1.

In addition, the combination of Bodell and Fujito is improper, since it would not have been obvious to one of ordinary skill in the art to replace the plurality of modulators of Fujito with the single modulator of Bodell as suggested by the Examiner. The plurality of modulators 1-1 through 1-N of Fujito each modulates a television signal to a carrier wave having a different frequency. The resultant plurality of modulated signals with different carrier frequencies are then multiplexed together into one signal. On the other hand, the single modulator 7 of Bodell appears to modulate a single multiplexed signal with a single carrier wave. Therefore, replacing the plurality of modulators 1-1 through 1-N with the single modulator 7 would render the transmission system of Fujito inoperable, since the single modulator 7 appears to only modulate a signal with a carrier signal of a single frequency and would not be able to modulate the plurality of television signals to a plurality of carrier signals all with different frequencies. The Federal Circuit has stated that if, in order to meet the limitations of a claim, a device in a prior art patent would have to be modified in a manner as to render it inoperable for its intended purpose, then in effect, that patent teaches away from the proposed modification. In re Gordon, 221 USPQ 1125, 1127 (Fed. Cir. 1984).

Also, the Examiner relies on LaGasse as disclosing a light source that outputs an unmodulated light and a Mach-Zehnder modulator. However, even if the Examiner reliance on

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this reference is correct, LaGasse fails to disclose or suggest the optical transmitter recited in claim 1.

As for claim 8, it is allowable over the references relied upon by the Examiner for the same reasons as set forth above in support of claim 1. That is, claim 8, like above claim 1, recites an optical transmitter operable to convert a FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in an optical frequency spectrum through optical modulation using the FM modulated signal as an original signal to send the optical-intensity-modulated signal to a receiving end, which feature is not disclosed or suggested in the references.

Because of the above mentioned distinctions, it is believed clear that claims 1-14 are allowable over the references relied upon by the Examiner. Furthermore, it is submitted that the distinctions are such that a person having ordinary skill in the art at the time of invention would not have been motivated to make any combination of the references of record in such a manner as to result in, or otherwise render obvious, the present invention as recited in claims 1-14. Therefore, it is submitted that claims 1-14 are clearly allowable over the prior art of record.

In view of the above amendments and remarks, it is submitted that the present application is now in condition for allowance. The Examiner is invited to contact the undersigned by telephone if it is felt that there are issues remaining which must be resolved before allowance of the application.

Respectfully submitted,

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and demodulates the FM modulated signal to reproduce the original frequency-division-multiplexed signal. The optical transmission system utilizes an FM gain in the FM transmission to improve the signal-to-noise power ratio (SNR) of the demodulated signal (i.e., the frequency-division-multiplexed signal), thereby enabling high-quality signal transmission.

Thus, the above-described optical transmission system can realize high-quality multi-channel signal transmission with an optical fiber.

However, the above-described system for optically transmitting an FM modulated signal has the following specific problems due to the properties of the FM modulated signal and the nonlinearity of an optical fiber.

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An FM modulation scheme increases a frequency deviation to acquire a greater FM gain, thereby enabling signal transmission of higher quality than other modulation schemes such as amplitude modulation. On the other hand, the increased frequency deviation requires a wider signal band. In addition, in the FM modulation scheme, linear distortion tends to occur under the influence of the group delay characteristic of a transmission line and the like (the characteristic that a propagation delay varies depending on a frequency). Therefore, the transmission line must be designed with particular attention. However, as a signal band becomes wider, the group delay variations in the band becomes more difficult to ~~be~~ sufficiently suppress~~ed~~.

In a general optical modulation scheme, the optical frequency spectrum of an optical signal is composed of a steep-shaped optical carrier component, which has narrow spectral line-width, and upper and lower sidebands, as shown in FIG. 12B. The upper and lower sidebands are geometrically similar to the frequency spectrum of a modulating signal. Therefore, if a wide-band signal like an FM modulated signal is used as a modulating signal in optical modulation, the optical frequency spectrum of the optical signal also becomes wider. The optical signal having such wide optical frequency spectrum becomes susceptible to the chromatic-dispersion of an optical fiber (the characteristic that a propagation delay varies depending on a wavelength). The affected optical signal component interacts with the optical carrier component to induce harmonic distortion in the FM modulated signal, resulting in waveform deterioration of the transmitted signal.

As is known from the above, the conventional optical transmission system has the specific problem that the quality of the transmitted signal is degraded due to the wide-band property of an FM modulated signal.

22 SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to provide an optical transmission system capable of narrowing the bandwidth of an FM modulated signal while increasing the frequency deviation

thereof to realize high-quality signal transmission.

The present invention has the following features to attain the object above.

A first aspect of the present invention is directed to a transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division multiplexing a plurality of signals, from a transmitting end to a receiving end. The transmission system comprises ~~comprising:~~

at the transmitting end,

a multiplexer for frequency-division multiplexing the plurality of signals to produce the frequency-division-multiplexed signal,

an FM modulator for converting the frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using the frequency-division-multiplexed signal as an original signal to output the frequency-modulated signal as an FM modulated signal, and

an optical transmitter for converting the FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in the optical frequency spectrum through optical modulation using the FM modulated signal as an original signal to send the optical-intensity-modulated signal to the receiving end. The transmission system also comprises ~~and~~

at the receiving end,

an optical receiver for receiving the optical-

intensity-modulated signal from the optical transmitter, and converting the optical-intensity-modulated signal into an electrical signal corresponding to the FM modulated signal through photodetection based on a square-law detection characteristic to output the electrical signal as a received FM modulated signal~~;~~, and an FM demodulator for demodulating the received FM modulated signal to reproduce the frequency-division-multiplexed signal.

As described above, in the first aspect, the FM modulated signal is obtained through frequency modulation using a frequency-division-multiplexed signal as an original signal. The FM modulated signal is converted into an optical-intensity-modulated signal at the transmitting end. The optical-intensity-modulated signal has an optical frequency spectrum in which upper and lower sidebands distribute geometrically similarly to the frequency spectrum of the original signal for the optical modulation and in which an optical carrier component is suppressed. Then, the optical-intensity-modulated signal is photodetected based on a square-law detection characteristic at the receiving end. At the receiving end, the optical transmission system thus obtains an FM modulated signal, having a frequency deviation twice as large as the one of the original FM modulated signal produced at the transmitting end, as a received FM modulated signal. In this manner, the optical

transmission system can narrow (reduce in half) the bandwidth of the FM modulated signal at the transmitting end while securing the frequency deviation thereof large enough to acquire a sufficient FM gain in FM demodulation. As a result, it is possible to prevent the waveform of the transmitted signal from being deteriorated due to the group delay characteristic of the electrical transmission line and the chromatic-dispersion of the optical transmission line, and to realize signal transmission of good quality.

According to a second aspect, in the first aspect, the optical transmitter includes

a light source for outputting an unmodulated light, and

an optical modulator for modulating the unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal. The optical modulator has ~~having~~ the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and is ~~being~~ biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the minimum.

As stated above, in the second aspect, the optical modulator used herein is an external optical modulator having the Mach-Zehnder interferometer structure. A modulating signal (an FM modulated signal) is applied to the optical modulator with respect to the "valley" where the output optical power is at the

minimum in the input-voltage vs. output-optical-power characteristic (which is periodic like a sine wave) of the optical modulator. The optical modulator thus produces an optical-intensity-modulated signal whose optical carrier component is suppressed. The suppression of the optical carrier component prevents the waveform from being deteriorated by the chromatic-dispersion of the optical transmission line. In addition, the optical-intensity-modulated signal has an optical frequency spectrum in which upper and lower sidebands distribute geometrically similarly to the frequency spectrum of the original signal for the optical modulation. Therefore, after the optical-intensity-modulated signal is square-law detected at the receiving end, the frequency deviation of the FM modulated signal is doubled, thereby making it possible to realize high-quality signal transmission.

According to a third aspect, in the second aspect, the transmission system further comprises:

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the unmodulated light with the frequency-divided FM modulated signal to produce the optical-intensity-modulated signal.

As described above, in the third aspect, the optical transmission system previously produces in the FM modulator ~~an~~ a FM modulated signal having a frequency deviation larger enough to acquire a desired FM gain. The optical transmission system then converts the FM modulated signal into a frequency-divided FM modulated signal, and next converts the frequency-divided FM modulated signal into an optical-intensity-modulated signal for transmission. This reduces the phase noise in the FM modulated signal to be optically transmitted and FM demodulated. As a result, high-quality signal transmission can be realized.

According to a fourth aspect, in the first aspect, the optical transmitter includes

a light source for outputting an unmodulated light,

an optical branching circuit for branching the unmodulated light fed from the light source into first and second unmodulated lights,

an optical modulator for modulating the first unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the maximum, and

an optical combining circuit for combining the optical-

intensity-modulated signal produced by the optical modulator and the second unmodulated light to cancel the optical carrier component of the optical-intensity-modulated signal with the second unmodulated light and output the optical-intensity-modulated signal whose optical carrier component is suppressed.

As stated above, in the fourth aspect, the optical modulator used herein is an external optical modulator having the Mach-Zehnder interferometer structure. A modulating signal (an FM modulated signal) is applied to the optical modulator with respect to the "peak" where the output optical power is at the maximum in the input-voltage vs. output-optical-power characteristic (being periodic like a sine wave) of the optical modulator. The optical modulator modulates the first unmodulated light with the applied modulated signal to produce an optical-intensity-modulated signal. The optical carrier component of the optical-intensity-modulated signal is then canceled by a second unmodulated light in the optical combining circuit. The optical carrier component of the optical-intensity-modulated signal is thus suppressed, and the optical frequency spectrum thereof has upper and lower sidebands distributing geometrically similarly to the frequency spectrum of the original signal for the optical modulation. Accordingly, it is possible to prevent the waveform of the transmitted signal from being deteriorated due to the chromatic-dispersion of an optical transmission line, and to increase the frequency deviation of the FM modulated signal by

square-law detecting the above-mentioned optical-intensity-modulated signal at the receiving end, which leads to high-quality signal transmission.

According to a fifth aspect, in the fourth aspect, the optical transmitter further includes an optical delay circuit, provided between the optical branching circuit and the optical combining circuit, for adjusting a propagation delay of at least one of the first unmodulated light, the second unmodulated light, and the optical-intensity-modulated signal produced by the optical modulator such that the second unmodulated light and the optical carrier component of the optical-intensity-modulated signal produced by the optical modulator are set in opposite phases to each other.

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As described above, in the fifth aspect, the optical-intensity-modulated signal produced by the optical modulator is combined with the second unmodulated light set in an opposite phase to the optical carrier component of the optical-intensity-modulated signal. The optical carrier component of the optical-intensity-modulated signal is thus canceled by the second unmodulated light. As a result ~~Resultantly~~, it is possible to produce an optical-intensity-modulated signal whose optical carrier component is suppressed.

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According to a sixth aspect, in the fourth aspect, the transmission system further comprises

a frequency-divider provided between the FM modulator and

the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the first unmodulated light with the frequency-divided FM modulated signal to produce the optical-intensity-modulated signal.

As stated above, in the sixth aspect, as in the third aspect, the optical transmission system previously produces in the FM modulator an FM modulated signal having a frequency deviation larger enough to acquire a desired FM gain, then converts the FM modulated signal into a frequency-divided FM modulated signal, and converts the signal into an optical-intensity-modulated signal for transmission. It is therefore possible to reduce the phase noise in the FM modulated signal to be optically transmitted and FM demodulated.

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According to a seventh aspect, in the first aspect, the transmission system further comprises

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical transmitter includes an optical modulator for producing the optical-intensity-modulated signal

through the optical modulation using the frequency-divided FM modulated signal as an original signal.

As described above, in the seventh aspect, the optical transmission system previously produces in the FM modulator an FM modulated signal having a frequency deviation larger enough to acquire a desired FM gain, then converts the FM modulated signal into a frequency-divided FM modulated signal, and next converts the signal into an optical-intensity-modulated signal for transmission. It is therefore possible to reduce the phase noise in the FM modulated signal to be optically transmitted and FM demodulated.

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An eighth aspect of the present invention is directed to an transmitter for use in a transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division-multiplexing a plurality of signals, from a transmitting end to a receiving end. The transmitter comprises ~~comprising:~~

a multiplexer for frequency-division multiplexing the plurality of signals to produce the frequency-division-multiplexed signal,

an FM modulator for converting the frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using the frequency-division-multiplexed signal as an original signal to output the frequency-modulated signal as an FM modulated signal, and

an optical transmitter for converting the FM modulated

signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in the optical frequency spectrum through optical modulation using the FM modulated signal as an original signal to send the optical-intensity-modulated signal to the receiving end.

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According to a ninth aspect, in the eighth aspect, the optical transmitter includes

a light source for outputting an unmodulated light, and

an optical modulator for modulating the unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the minimum.

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According to a tenth aspect, in the ninth aspect, the transmitter further comprises

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the unmodulated light with the frequency-divided FM modulated signal to produce

the optical-intensity-modulated signal.

According to an eleventh aspect, in the eighth aspect, the optical transmitter includes/,

a light source for outputting an unmodulated light/,

an optical branching circuit for branching the unmodulated light fed from the light source into first and second unmodulated lights/,

an optical modulator for modulating the first unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the maximum/, and

an optical combining circuit for combining the optical-intensity-modulated signal produced by the optical modulator and the second unmodulated light to cancel the optical carrier component of the optical-intensity-modulated signal with the second unmodulated light, and output the optical-intensity-modulated signal whose optical carrier component is suppressed.

According to a twelfth aspect, in the eleventh aspect, the optical transmitter further includes an optical delay circuit, provided between the optical branching circuit and the optical combining circuit, for adjusting a propagation delay of at least

one of the first unmodulated light, the second unmodulated light, and the optical-intensity-modulated signal produced by the optical modulator such that the second unmodulated light and the optical carrier component of the optical-intensity-modulated signal produced by the optical modulator are set in opposite phases to each other.

According to a thirteenth aspect, in the eleventh aspect, the transmitter further comprises

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the first unmodulated light with the frequency-divided FM modulated signal to produce the optical-intensity-modulated signal.

According to a fourteenth aspect, in the eighth aspect, the transmitter further comprises

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical transmitter includes an optical modulator for producing the optical-intensity-modulated signal

through optical modulation using the frequency-divided FM modulated signal as an original signal.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing the configuration of an optical transmission system according to a first embodiment of the present invention;

FIG. 2A is a schematic diagram showing the frequency spectrum of an FM modulated signal outputted from an FM modulator in the optical transmission system according to the first embodiment;

FIG. 2B is a schematic diagram showing the optical frequency spectrum of an optical signal outputted from an optical modulator in the optical transmission system according to the first embodiment;

FIG. 2C is a schematic diagram showing the frequency spectrum of an FM modulated signal outputted from an optical receiver in the optical transmission system according to the first embodiment;

FIG. 3 is a schematic diagram used to explain optical modulation performed by the optical modulator in the optical

end, the light source 103 and the optical modulator 104 constitute an optical transmitter 20a, and the optical transmitter 20a, the multiplexer 100, and the FM modulator 101 constitute a transmitter 10a. In addition, the optical receiver 106 at the receiving end is constituted by a photodetector such as photodiode for converting an optical signal into an electrical signal through photodetection based on a square-law detection characteristic, and a preamplifier for amplifying the electrical signal fed from the photodetector.

Next, referring to FIGS. 2A to 2C, the operation of the present embodiment shown in FIG. 1 is described. FIGS. 2A to 2C ~~are~~ schematically illustrate the frequency spectrums of respective signals in the optical transmission system in FIG. 1. FIG. 2A shows the frequency spectrum of an output signal of the FM modulator 101. FIG. 2B shows the optical frequency spectrum of an output signal (optical signal) of the optical modulator 104. FIG. 2C shows the frequency spectrum of an output signal of the optical receiver 106. In the optical transmission system shown in FIG. 1, the multiplexer 100 frequency-division multiplexes a plurality of signals, and outputs the resultant signal to the FM modulator 101. The FM modulator 101 converts the frequency-division-multiplexed signal into an FM modulated signal through frequency modulation. The FM modulated signal has a frequency spectrum as shown in FIG. 2A in which a carrier frequency is fc and a frequency deviation is ΔF. After that, the FM modulator

outputs the FM modulated signal to the electrical transmission line 102. The light source 103 outputs an unmodulated light. The optical modulator 104 receives the unmodulated light from the light source 103 and the FM modulated signal through the electrical transmission line 102, then modulates the unmodulated light with the FM modulated signal, and outputs an optical signal whose optical carrier component is suppressed. The optical modulator 104 has the Mach-Zehnder interferometer structure, for example, and is biased at the "valley" in its input-voltage vs. output-optical-power characteristic, where the output optical power is at the minimum, as shown in FIG. 3. The FM modulated signal is applied to the optical modulator 104 with respect to the voltage of an operating point 1001 which is set by the above-mentioned bias. The optical modulator 104 thus produces an optical-intensity-modulated signal (hereinafter, referred to as "optical signal") having the optical frequency spectrum in which an optical carrier component is suppressed as shown in FIG. 2B. The optical receiver 106 receives the optical signal through the optical transmission line 105, and square-law detects the signal to convert into an FM modulated signal having the frequency spectrum as shown in FIG. 2C, that is, an FM modulated signal whose carrier frequency is 2fc and whose frequency deviation is 2*ΔF. The optical receiver 106 then outputs the FM modulated signal to the FM demodulator 107. The FM demodulator 107 demodulates the FM modulated signal to reproduce the original

frequency-division-multiplexed signal.

An FM modulation scheme can raise an FM gain by increasing a frequency deviation, and improve the signal-to-noise ratio (SNR) of a demodulated signal. On the other hand, the increase in frequency deviation extends the spectrum bandwidth of an FM modulated signal, and also requires a wider band of a transmission line. The group delay characteristic of the transmission line with such wide band affects the FM modulated signal, to cause linear distortion thereof in some cases. That is, as the bandwidth of an FM modulated signal is wider, waveform distortion thereof increases. In short, a frequency deviation in FM modulated signal transmission has a trade-off relation between noise characteristic and waveform distortion of an FM modulated signal. Hence, the wide-band FM transmission system is difficult to optimally design.

The optical transmission system in FIG. 1 converts an FM modulated signal into an optical signal whose optical carrier is suppressed, and then optically transmits and square-law detects the optical signal, thus producing an FM modulated signal having a frequency deviation (or frequency bandwidth) twice as large as the one of the original FM modulated signal. Therefore, the frequency deviation of the FM modulated signal outputted from the FM modulator 101 is set to be half of the frequency deviation essentially required to acquire a predetermined FM gain in FM demodulation. The optical transmission system thus reduces the

ABSTRACT OF THE DISCLOSURE

In an optical transmission system, a multiplexer ~~100~~ frequency-division-multiplexes a plurality of signals, and outputs the resultant signal to an FM modulator ~~101~~. The FM modulator ~~101~~ converts the frequency-division-multiplexed signal into an FM modulated signal through frequency modulation using the frequency-division-multiplexed signal as an original signal. A frequency-divider ~~108~~ converts the FM modulated signal into a frequency-divided FM modulated signal whose frequency is $1/2^n$ (n is an integer of not less than 1) the frequency of the FM modulated signal. An optical modulator ~~104~~ has a predetermined input-voltage vs. output-optical-power characteristic, and is biased at the minimum point (voltage) about the output optical power. The optical modulator ~~104~~ modulates an unmodulated light fed from a light source ~~103~~ with the applied frequency-divided FM modulated signal to produce an optical signal whose optical carrier component is suppressed, and sends the optical signal to an optical transmission line ~~105~~. An optical receiver ~~106~~ receives the optical signal, and square-law detects the signal to convert into an FM modulated signal. An FM demodulator ~~107~~ demodulates the FM modulated signal to reproduce the original frequency-division-multiplexed signal. This configuration makes it possible to narrow the bandwidth of an FM modulated signal while increasing the frequency deviation thereof, and realize high-quality signal transmission as a result.

WHAT IS CLAIMED IS:

1. (Amended) A transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division multiplexing a plurality of signals, [from a transmitting end to a receiving end,] said transmission system comprising:

a [at said] transmitting end[,] comprising

a multiplexer operable to [for] frequency-division multiplex the [multiplexing said] plurality of signals to produce [said] the frequency-division-multiplexed signal[;],

a~~n~~ FM modulator operable to convert the [for converting said] frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using [said] the frequency-division-multiplexed signal as an original signal to output the [said] frequency-modulated signal as a~~n~~ FM modulated signal[;], and

an optical transmitter operable to convert the [for converting said] FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in [the] an optical frequency spectrum through optical modulation using [said] the FM modulated signal as an original signal to send [said] the optical-intensity-modulated signal to [said] a receiving end[,]; and

[at] said receiving end[,] comprising

an optical receiver operable to receive the [for receiving said] optical-intensity-modulated signal from said optical transmitter, and convert the [converting said] optical-intensity-modulated signal into an

electrical signal corresponding to [said] the FM modulated signal through photodetection based on a square-law detection characteristic to output [said] the electrical signal as a received FM modulated signal[;], and an FM demodulator operable to demodulate the [for demodulating said] received FM modulated signal to reproduce [said] the frequency-division-multiplexed signal.

2. (Amended) The transmission system according to claim 1, wherein said optical transmitter comprises [includes]:

a light source being operable to output [for outputting] an unmodulated light; and

an optical modulator being operable to modulate the [for modulating said] unmodulated light with [said] the FM modulated signal to produce [said] the optical-intensity-modulated signal, said optical modulator having a [the] Mach-Zehnder interferometer structure with a predetermined input-voltage versus [vs.] output-optical-power characteristic, and being biased in [said] the input-voltage versus [vs.] output-optical-power characteristic such that an [the] output optical power is at a [the] minimum.

3. (Amended) The transmission system according to claim 2, further comprising[,] a frequency-divider provided between said FM modulator and said optical transmitter, said frequency-divider being operable to convert the [for converting said] FM modulated signal outputted from said FM modulator into a frequency-divided FM

modulated signal whose frequency is $1/2^n$ [the] of a frequency of The [said] FM modulated signal, [said] n being an integer of not less than 1,

wherein said optical modulator modulates [said] the unmodulated light with [said] the frequency-divided FM modulated signal to produce [said] The optical-intensity-modulated signal.

4. (Amended) The transmission system according to claim 1, wherein said optical transmitter comprises [includes]:

a light source being operable to output [for outputting] an unmodulated light;

an optical branching circuit being operable to branch the [for branching said] unmodulated light fed from said light source into a first unmodulated light and a second unmodulated light[s];

an optical modulator being operable to modulate the [for modulating said] first unmodulated light with [said] the FM modulated signal to produce [said] the optical-intensity-modulated signal, said optical modulator having a [the] Mach-Zehnder interferometer structure with a predetermined input-voltage versus [vs.] output-optical-power characteristic, and being biased in [said] the input-voltage versus [vs.] output-optical-power characteristic such that [the] an output optical power is at a [the] maximum; and

an optical combining circuit being operable to combine the [for combining said] optical-intensity-modulated signal produced by said optical modulator and [said] the second unmodulated light to cancel [the] an optical carrier component of [said] the optical-intensity-modulated signal with [said] the second unmodulated light and output the [said] optical-

intensity-modulated signal whose optical carrier component is suppressed.

(Amended)

5. The transmission system according to claim 4, wherein said optical transmitter further comprises [includes] an optical delay circuit[,] provided between said optical branching circuit and said optical combining circuit, said optical delay circuit being operable to adjust [for adjusting] a propagation delay of at least one of [said] the first unmodulated light, the [said] second unmodulated light, and [said] the optical-intensity-modulated signal produced by said optical modulator such that [said] the second unmodulated light and [said] the optical carrier component of [said] the optical-intensity-modulated signal produced by said optical modulator are set in opposite phases to each other.

(Amended)

6. The transmission system according to claim 4, further comprising[,]

a frequency-divider provided between said FM modulator and said optical transmitter, said frequency-divider being operable to convert the [for converting said] FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ of a [the] frequency of the [said] FM modulated signal, [said] n being an integer of not less than 1,

wherein said optical modulator modulates [said] the first unmodulated light with [said] the frequency-divided FM modulated signal to produce [said] the optical-intensity-modulated signal.

7. (Amended) The transmission system according to claim 1, further comprising[,] a frequency-divider provided between said FM modulator and said optical transmitter, said frequency-divider being operable to convert the [for converting said] FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ of [the] a frequency of the [said] FM modulated signal, [said] n being an integer of not less than 1,

wherein said optical transmitter comprises [includes] an optical modulator being operable to produce the [for producing said] optical-intensity-modulated signal through the [said] optical modulation using the [said] frequency-divided FM modulated signal as an original signal.

8. A transmitter for use in a transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division-multiplexing a plurality of signals, said transmitter [from a transmitting end to a receiving end,] comprising:

a multiplexer being operable to [for] frequency-division multiplex the [multiplexing said] plurality of signals to produce the [said] frequency-division-multiplexed signal;

an FM modulator being operable to convert the [for converting said] frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using the [said] frequency-division-multiplexed signal as an original signal to output the [said] frequency-modulated signal as an FM modulated signal; and

an optical transmitter being operable to convert the ~~for converting said~~ FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in an ~~the~~ optical frequency spectrum through optical modulation using the ~~said~~ FM modulated signal as an original signal to send the ~~said~~ optical-intensity-modulated signal to a ~~said~~ receiving end.

9. The transmitter according to claim 8, wherein said optical transmitter comprises ~~includes~~:

a light source being operable to output ~~for outputting~~ an unmodulated light; and

an optical modulator being operable to modulate the ~~for modulating said~~ unmodulated light with the ~~said~~ FM modulated signal to produce the ~~said~~ optical-intensity-modulated signal, said optical modulator having a ~~the~~ Mach-Zehnder interferometer structure with a predetermined input-voltage versus ~~vs.~~ output-optical-power characteristic, and being biased in the ~~said~~ input-voltage versus ~~vs.~~ output-optical-power characteristic such that an ~~the~~ output optical power is at a ~~the~~ minimum. √

10. The transmitter according to claim 9, further comprising~~,~~ a frequency-divider provided between said FM modulator and said optical transmitter, said frequency-divider being operable to convert the ~~for converting said~~ FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ of a ~~the~~ frequency of the ~~said~~ √

FM modulated signal, ~~said~~ n being an integer of not less than 1,

wherein said optical modulator modulates ~~said~~ The unmodulated light with ~~said~~ the frequency-divided FM modulated signal to produce ~~said~~ the optical-intensity-modulated signal.

11. The transmitter according to claim 8, wherein said optical transmitter comprises ~~includes~~:

a light source being operable to output ~~for outputting~~ an unmodulated light;

an optical branching circuit being operable to branch the ~~for branching said~~ unmodulated light fed from said light source into a first unmodulated light and a second unmodulated light~~s~~;

an optical modulator being operable to modulate the ~~for modulating said~~ first unmodulated light with ~~said~~ the FM modulated signal to produce ~~said~~ The optical-intensity-modulated signal, said optical modulator having a ~~the~~ Mach-Zehnder interferometer structure with a predetermined input-voltage versus ~~vs.~~ output-optical-power characteristic, and being biased in ~~said~~ the input-voltage versus ~~vs.~~ output-optical-power characteristic such that ~~the~~ an output optical power is at a ~~the~~ maximum; and

an optical combining circuit being operable to combine The ~~for combining said~~ optical-intensity-modulated signal produced by said optical modulator and ~~said~~ the second unmodulated light to cancel ~~the~~ an optical carrier component of ~~said~~ the optical-intensity-modulated signal with ~~said~~ the second unmodulated light, and output the ~~said~~ optical-intensity-modulated signal whose optical carrier component is

suppressed.

12. The transmitter according to claim 11, wherein said optical transmitter further comprises ~~includes~~ an optical delay circuit~~,~~ provided between said optical branching circuit and said optical combining circuit, said optical delay circuit being operable to adjust ~~for adjusting~~ a propagation delay of at least one of ~~said~~ the first unmodulated light, the ~~said~~ second unmodulated light, and the ~~said~~ optical-intensity-modulated signal produced by said optical modulator such that the ~~said~~ second unmodulated light and the ~~said~~ optical carrier component of ~~said~~ the optical-intensity-modulated signal produced by said optical modulator are set in opposite phases to each other.

13. The transmitter according to claim 11, further comprising~~,~~

a frequency-divider provided between said FM modulator and said optical transmitter, said frequency-divider being operable to convert the ~~for converting said~~ FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ of a ~~the~~ frequency of the ~~said~~ FM modulated signal, ~~said~~ n being an integer of not less than 1,

wherein said optical modulator modulates ~~said~~ the first unmodulated light with ~~said~~ the frequency-divided FM modulated signal to produce ~~said~~ the optical-intensity-modulated signal.

14. The transmitter according to claim 8, further

comprising[,] a frequency-divider provided between said FM modulator and said optical transmitter, said frequency-divider being operable to convert the [for converting said] FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ of a [the] frequency of the [said] FM modulated signal, [said] n being an integer of not less than 1,

wherein said optical transmitter includes an optical modulator being operable to produce the [for producing said] optical-intensity-modulated signal through the [said] optical modulation using the [said] frequency-divided FM modulated signal as an original signal.

FIG. 2A

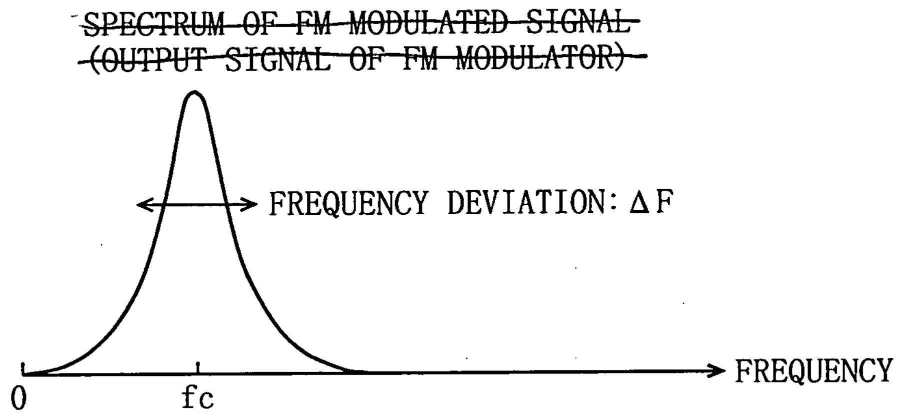

FIG. 2B

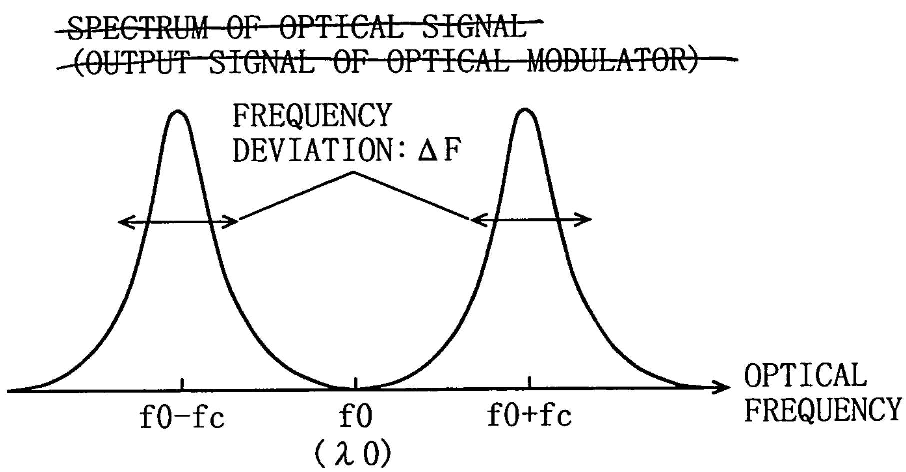

FIG. 2C

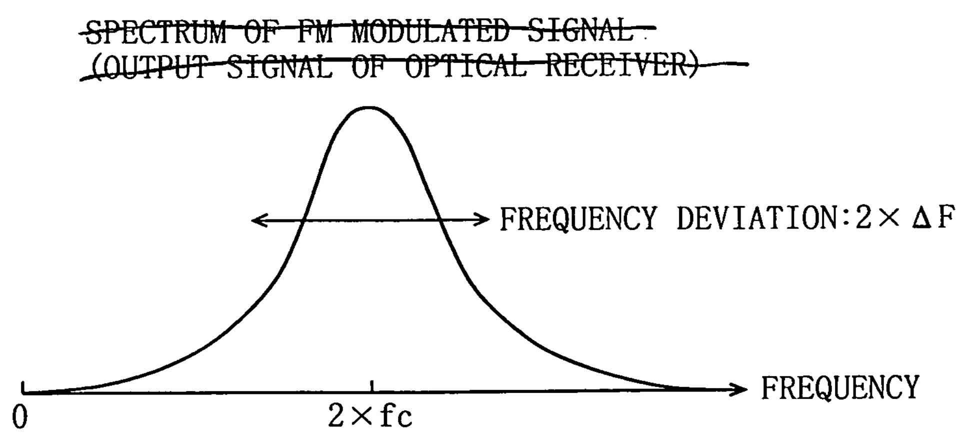

FIG. 5A

~~SPECTRUM OF SIGNAL OUTPUTTED FROM FM MODULATOR~~

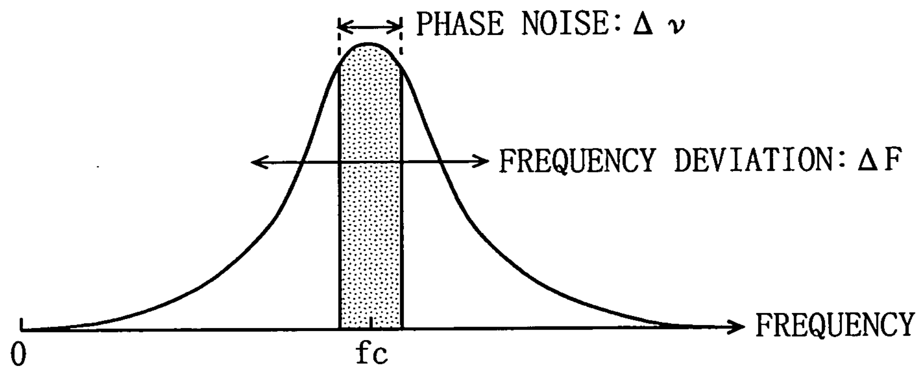

FIG. 5B

~~SPECTRUM OF SIGNAL OUTPUTTED FROM FREQUENCY DIVIDER~~

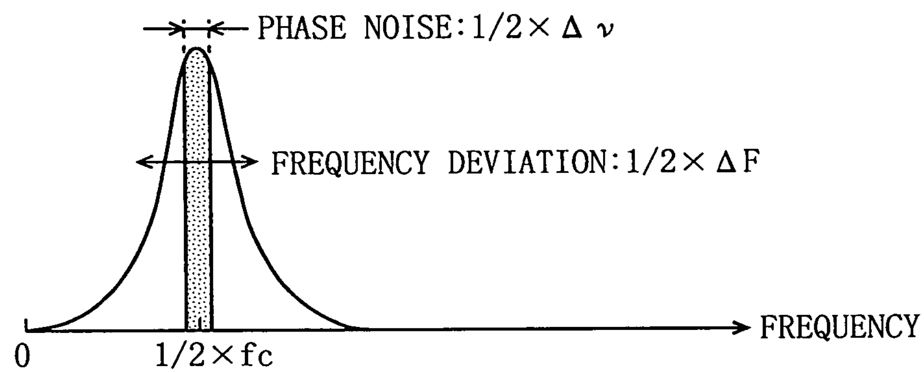

FIG. 5C

~~SPECTRUM OF SIGNAL OUTPUTTED FROM OPTICAL RECEIVER~~

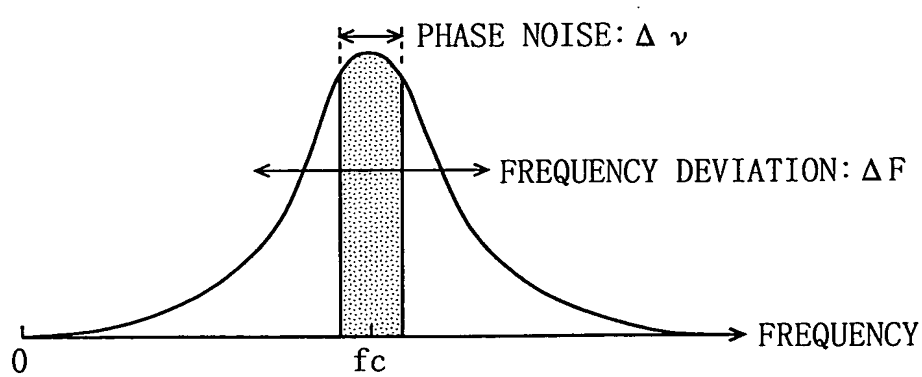

FIG. 6A

~~SPECTRUM OF SIGNAL OUTPUTTED FROM FM MODULATOR~~

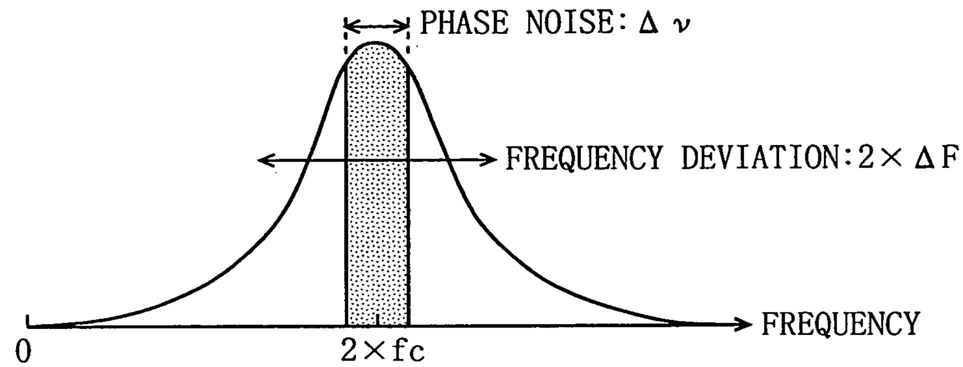

FIG. 6B

~~SPECTRUM OF SIGNAL OUTPUTTED FROM FREQUENCY DIVIDER~~

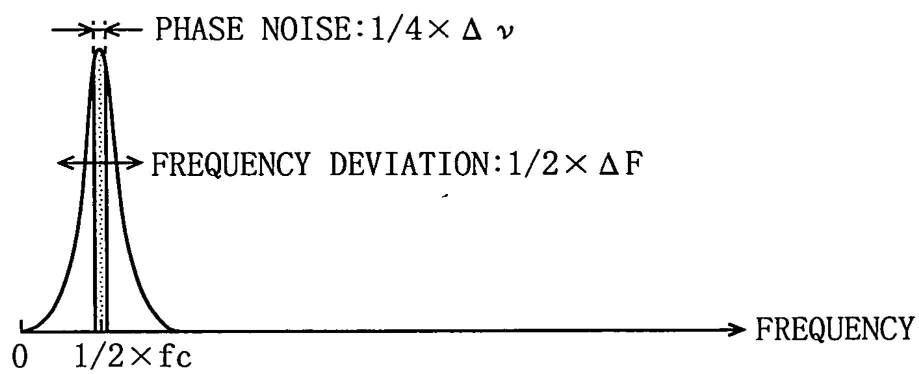

FIG. 6C

~~SPECTRUM OF SIGNAL OUTPUTTED FROM OPTICAL RECEIVER~~

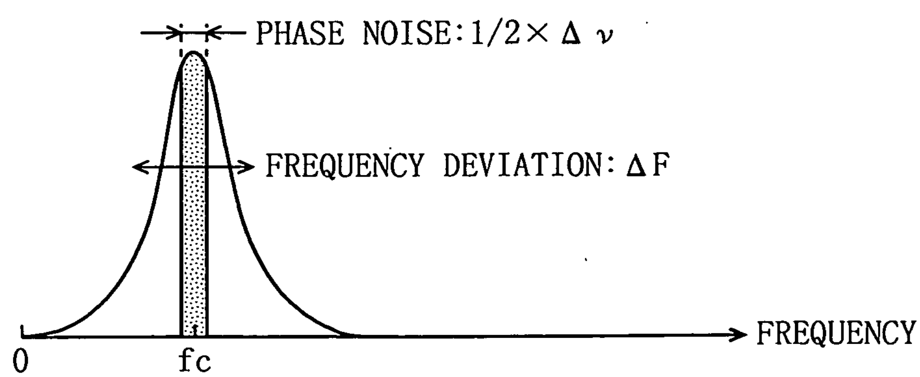

FIG. 10A

~~SPECTRUM OF OPTICAL SIGNAL OUTPUTTED FROM OPTICAL MODULATOR~~

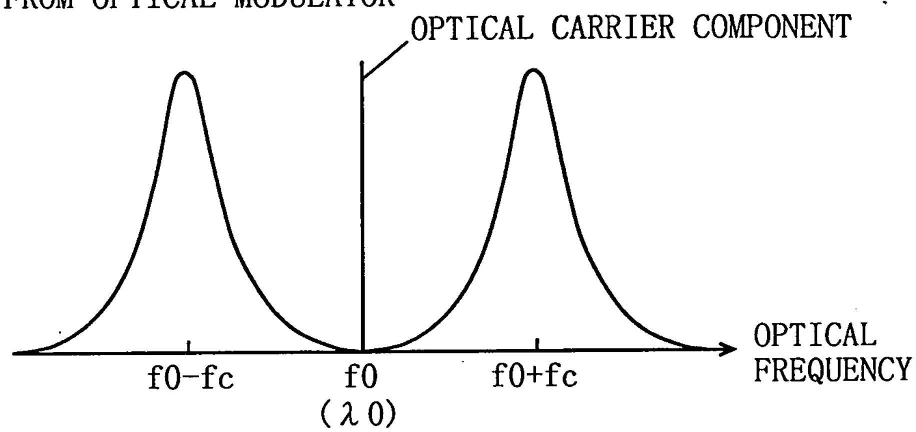

FIG. 10B

~~SPECTRUM OF OUTPUT LIGHT (UNMODULATED LIGHT) FROM OPTICAL BRANCHING CIRCUIT~~

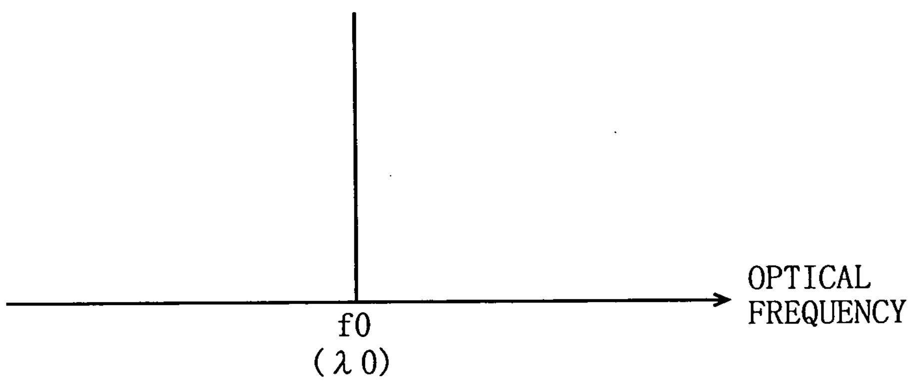

FIG. 10C

~~SPECTRUM OF OPTICAL SIGNAL OUTPUTTED FROM OPTICAL COMBINING CIRCUIT~~

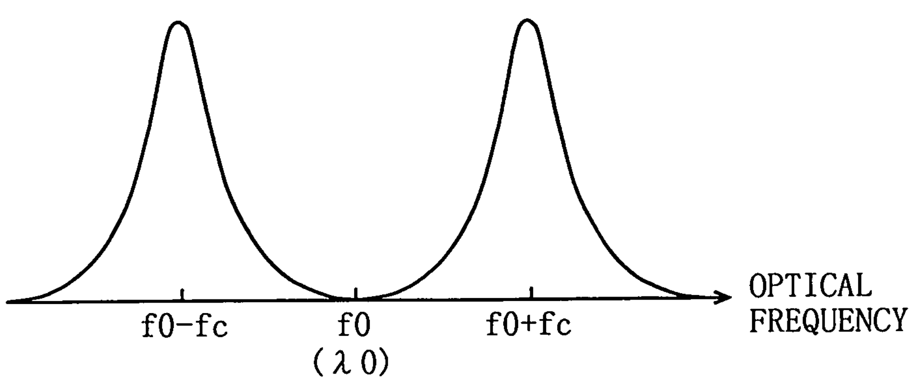

FIG. 12A PRIOR ART

~~SPECTRUM OF FM MODULATED SIGNAL~~
~~(OUTPUT SIGNAL OF FM MODULATOR)~~

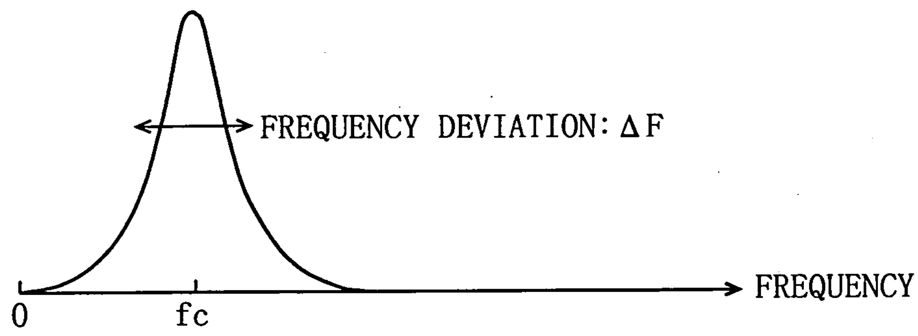

FIG. 12B PRIOR ART

~~SPECTRUM OF OPTICAL SIGNAL~~
~~(OUTPUT SIGNAL OF OPTICAL TRANSMITTER)~~

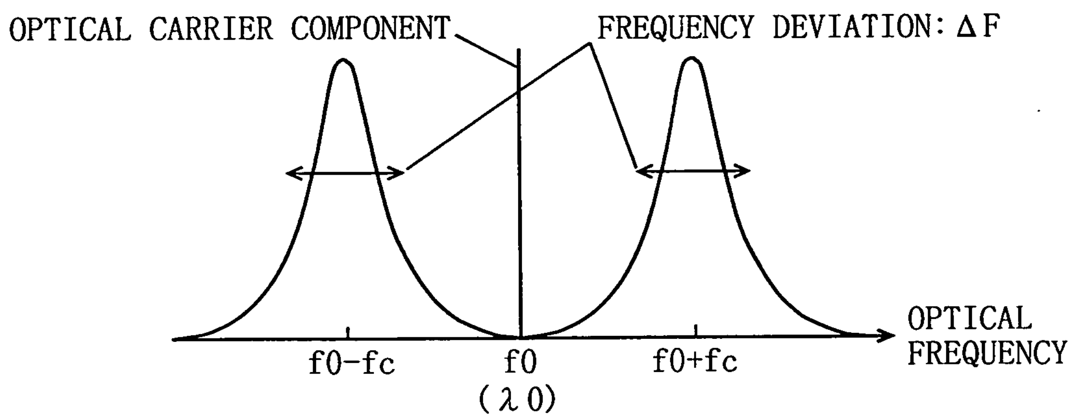

FIG. 12C PRIOR ART

~~SPECTRUM OF FM MODULATED SIGNAL~~
~~(OUTPUT SIGNAL OF OPTICAL RECEIVER)~~